The Ecology and Acoustic Behavior of Minke Whales in the Hawaiian and other Pacific Islands

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LONG-TERM GOALS

The long-term goals of this research project are to develop and use methods to collect passive acoustic data that will improve our understanding of ecology and behavior of minke whales (*Balaenoptera acutorostrata*) in their presumed breeding habitats around the Hawaiian Islands and other subtropical Pacific areas. Ultimately, the new information and methods resulting from this project will provide new research methods and a better understanding of biology of minke whales so that more effective management and conservation practices can be implemented.

OBJECTIVES

The overall objectives were to use passive acoustic methods to investigate minke whale acoustic ecology and behavior in sub-tropical North Pacific islands areas by monitoring a unique vocalization known as the 'boing'. Our main field research objectives were to collect data concurrently from two passive acoustic systems: 1) a quiet research vessel towing a hydrophone array; 2) a U.S. Navy fixed seafloor hydrophone array located in the primary study site. We supplemented these data with towed hydrophone array data and autonomous recorder data collected by our collaborators in other island areas of the north Pacific for comparison. Secondary goals were to develop new processing analytical methods to review and analyze the abundance of acoustic data collected from fixed seafloor hydrophones, towed hydrophone arrays and autonomous recorders.

Our specific objectives were to use vessel-based passive acoustic methods to collect data to estimate the density and abundance of minke whales at our study site. A second objective was to investigate minke whale acoustic behaviors (including the effects of noise from our survey vessel on the acoustic behavior of minke whales) so that biases in the analysis results could be assessed. The third objective was to investigate the population structure of minke whales by measuring and comparing acoustic characteristics of boings recorded at our main study area in the Hawaiian Islands and other regions such as the Northern Mariana Islands (NMI) and regions inbetween.

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APPROACH

This effort is a partnership with several researchers and institutions working on related efforts. These include Stephen Martin (SPAWAR), Len Thomas and Vincent Janik (Univ. of St. Andrews) and Eva Nosal (Univ. of Hawaii-SOEST). Other (unfunded) collaborators include John Hildebrand and Amanda Cummings (SIO-Applied Physics Lab). Bio-Waves was responsible for vessel-based surveys and validation efforts as well as all data analysis of towed array and autonomous recorder data.

We conducted combined visual and acoustic line-transect surveys of minke whales at our study site off of Kauai. The study site is a large (2055 km^2) rectangular shaped region that includes areas of deep (up 4500 m) ocean waters located to the northwest of the island of Kauai (Fig. 1). This study area was chosen because it is part of the Pacific Missile Range Facility (PMRF) and is outfitted with several seafloor hydrophone arrays. Concurrent with the vessel survey effort, acoustic data were recorded and processed (by S. Martin) from 15 to 17 hydrophones from the BSURE seafloor array. These data were post-processed using Matlab scripts developed to semi-automatically localize and estimate the density of boings produced by minke whales.

Visual and acoustic line-transect surveys were conducted from an acoustically quiet 87 ft. motor-sailing research vessel (R/V Dariabar). This vessel was designed to conduct passive acoustic research and had variable-pitch propeller to reduce cavitation noise when needed. A two-element, towed hydrophone array was deployed throughout on effort periods of the survey. Boings from minke whales were monitored and processed in real-time using ISHMAEL, Pamguard and Whaletrack II software for localization, plotting, and data-logging. Visual surveys were conducted (whenever sea and sighting conditions allowed) using standard line-transect protocols. All acoustic data were recorded to hard drives for post-processing and archival purposes.

Localizations of minke whales were processed in real-time from acoustic data collected from the towed hydrophone array. These data were post-processed using a custom developed program called 'Boinger' developed jointly by St Andrews and Bio-Waves Inc. Boinger was developed to allow a detailed review and re-analysis the towed array acoustic localization data. The program was written for Matlab and uses .wav files and an MS-Access database recorded during the towed array survey as data inputs. Data outputs include localization times, geographic locations and perpendicular distances from the survey track-line. Clips of boings and detailed measurements of boing characteristics are also provided as outputs for use in identification of individuals and acoustic characterization of boings for population comparisons. The boinger outputs and other data were imported into the program 'Distance' to estimate the density of calling animals. These density estimates will be used to calculate average boing production rates of minke whales in the study area which are needed for the spatially explicit capture-recapture methods that are being developed as part of the related DECAF effort (Marques et al. 2010).

Boing characteristics were measured from boings recorded by Bio-Waves in the PMRF-Kauai and NMI study area. In addition, we obtained samples from HARP recordings made off Wake Island, and Midway Island (both provided courtesy of John Hildebrand/SIO). These two islands are located at in between the Hawaiian Islands and the NMI (Figure 2). We used selective criteria for determining independence of samples as well as randomly sub-sampling data to provide equal sample sizes of approximately 60 boings from each area. Boings were clipped from recordings and 48 variables were measured semi-automatically using the Matlab bio-acoustic analysis program 'Osprey' (developed by Dave Mellinger/Holger Klinck, OSU). Measurements from these four areas were compared in 2011

using a random forest tree analyses. This robust non-parametric, tree based, statistical analysis allows a simple and intuitive method to compare and identify features of boings that are important in elucidating differences among the samples from these areas. The random forest analysis was used to determine if the boings could be accurately classified to their respective geographic regions. 2011 results indicated that boings from the four disparate geographic regions (Kauai , NMI, Wake or Midway Islands) are distinct from one another. Boings recorded from Kauai were the most likely to be confused with boings recorded from the NMI whereas boings from Wake had the highest classification scores, indicating these were the most distinctive.

There were some confounding factors in this analysis due to the fact that some areas used different recording methods (e.g. towed hydrophone arrays for Kauai and the Mariana Islands versus autonomous bottom recorders for Midway and Wake Island).   In general, boings recorded from areas using the same recording methods were more likely to be erroneously attributed to an area using those methods (except for Wake Island, which was most often confused with the NMI, the closest of the three other locations). Therefore in 2011 we performed a random forest analysis to evaluate how well boings could be classified to recording method rather than geographic region. The results of this analysis showed that 84% of boings recorded using the autonomous recorder and 82% of boings recorded using the towed array could be classified correctly to the recording method. This suggests that recording method may have an effect on determining which boing characteristics were most important in the classification models. We believe that that the higher misclassification rates between the NMI and Kauai are likely due to the similar recording methods used. Because of this, in 2012 we decided to re-run the analysis with boings from just the Kauai and NMI study sites.

WORK COMPLETED

To date, we conducted non-systematic vessel based acoustic surveys in 2009, and systematic acoustic/visual line-transect surveys for 4 weeks over a 2.5 month period in spring 2010. A total of 13 days of survey effort resulting in four complete surveys of the study area resulting in a total of 1520 km of line-transect (mean of 380 km for each survey) were completed, (for additional details see Norris 2010 annual report).   Post-processing of these data in 2011 resulted in approximately 50 localizations, some of which were determined to be duplicates (due to repeated sampling of the same region during the transect 'corners'), and were excluded from the analysis. Density analyses for the Kauai survey and earlier (2007) large scale acoustic-visual surveys conducted in the NMI study area. Boing measurements made in 2011 were used in the random forest geographic comparison of boings for Kauai and the NMI study areas (other regions were excluded).

Presentations, Conferences and Workshops Attended.
Results from various aspects of this project were presented by P.I. Tom Norris at numerous meetings:

1.) 2nd Pan-American/Iberian Meeting on Acoustics**,** Cancun, Mexico 15-19 November 2010 (oral);

2.) The Animal Communication Workshop, Cornell University, Ithaca, NY, 2-5 August; (poster);

3.) Density, Localization and Classification workshop, Mt. Hood, Oregon 22-25 August 2011 (oral).

Since the last annual report Mr. Norris presented an update of the project at the Acoustic Ecology Session (which he co-chaired) at the ASA meeting in San Diego, CA. November 2011 and a poster at the Society for Marine Mammalogy meeting in Tampa Bay, Florida in late November, where he also attended several workshop relevant to the research topics of this project.

RESULTS

Line-transect/Density Estimation

The (over 1600) minke whale recorded during towed-array acoustic surveys were processed in 2011 resulting in approximately 50 localized calling minke whales. Each localization was carefully reviewed by a data analyst and during the review, we discovered that several localizations occurred outside the study area, and others 'possibly' (due to the left/right ambiguity inherent in towed array localizations) occurred outside the study area. The localizations (and associated distances) that occurred outside the study area were eliminated from the subsequent 2012 line-transect analysis and those with left/right ambiguity were incorporated into the line-transect analysis by using the probability (50%) of them occurring inside or outside the study area (for additional details see report by St. Andrews project partners Janik and Thomas). Upon inspection of the histograms of the distances of acoustic localizations from the trackline, it was evident that there was significant decrease in the number of detections close to the trackline. Two possible explanations for this pattern are that calling minke whales were avoiding the survey vessel (evasive movement) and/or they were reducing their vocalization rates when the survey vessel approached closely (reduction of vocalizations). Based on these 2 possibilities, two detection functions were modeled (figures 3a and 3b), resulting in density estimates of 27.51 (C.V. 19.04%) and 37.08 (C.V. 20.15%) animals per 10,000 km^2, respectively (Table 2). The resulting line-transect density estimates were used to demonstrate that a boing rate per animal could be estimated for use in the SECR density estimation methods (developed by project partners, Len Thomas, from St. Andrews, and Steve Martin from SPAWAR Systems San Diego).

In 2012, line-transect density estimates of calling minke whales were also calculated for the much larger 585,500 km^2 NMI study area. Distance sampling methods (using the program Distance) were used to model detection functions and estimate densities. The same pattern of a decrease in the number of localization near the trackline that occurred in the Kauai study was evident in the histogram of distances from the trackline for the NMI data. Therefore, two detection functions were modeled (one for evasive movement and one for reduced calling) and density estimate were calculated using these (Table 2). The estimates of 6.73 (C.V. 25%) and 5.83 (C.V. 25%) were about five times less than those for the Kauai study site.

Effects of Vessel Noise on Vocalization Rates

No additional work has been conducted on this topic since the last report.

Boing Analysis and Geographic Comparisons

For the 2012 analysis, we excluded the Wake and Midway boings, and re-ran the random forest analyses for the NMI (n=68) and Kauai (n=70). Results indicated that boings could be classified to their respective regions with 81% and 85% correct classification scores respectively (Table 2). Results indicate that boings can be classified boings to their respective geographic locations with good success.

Fast Research Vessel Validation work

No additional work was conducted on this topic since the last report.

IMPACT / APPLICATIONS

Acoustic based line-transect surveys were used to derive density estimates of calling minke whales in the Kauai (PMRF) study area and the much larger (300x) NMI Study area. Obtaining minimum density estimate for minke whales in these areas is important because, to date, there are no estimates of minke whale abundance either the Hawaiian or the Northern Marianas Island regions. Both of these areas are used extensively by the Navy for training and other exercises. Another important application of this study is that the resulting line-transect density estimates can be used to calculate an average. boing (call) rates over the period of the study, simply by dividing average boing density (obtained from PMRF hydrophone array data) by the number of animals estimated from the acoustic line transect surveys, for concurrent time periods sampled. Call rates are critical for estimating densities of calling animals from acoustic data collected from fixed hydrophones. An example of this approach (and a preliminary boing call rate) was presented at the ONR review meeting in April 2012. Density estimates are the most basic information needed for marine mammals and are essential for effective mitigation of human activities and management of this federally protected species.

The software and scripts that we developed (with St. Andrews project partners) to semi-automate the line-transect and boing characterization analysis can be used to post-process data for localizations and measurement of acoustic characteristics of minke whale boings that are recorded in other Navy operational and training areas where North Pacific minke whales occur.

In spite of being first described by Navy sponsored researchers just over fifty years ago (Wenz, 1964), the acoustic characteristics of minke whale calls are still poorly understood for populations in the North Pacific. Our research has resulted in the discover that there are several measurable acoustic characteristics of the boings that can be used to reliably classify boings recorded from disparate geographic areas to a specific region. We have also investigated the effects of using different recording methods with preliminary results indicating that this must be accounted for when making comparisons of samples collected using different methods. The will help to better designing and analyzing results of future studies. The results of the boing comparisons indicate that some level of population structure exists across these areas and is an initial indication of the relative degree of mixing of minke whales in these disparate ocean-basin wide regions. These findings will help to better define, and therefore manage this population of wide-ranging marine mammals.

In summary results of our efforts are providing important information about the distribution, abundance, population structure and acoustic behavior of a vocally active species that is difficult if not impossible to study visually in the Central and western subtropical Pacific. The analytical tools we have developed can be applied to other data that have been, or will be collected, to provide important information on the abundance, distribution and population structure of minke whales and other species with similar acoustic behaviors. Finally our results will be used as inputs in related efforts that to develop statistical methods to use data collected from seafloor hydrophones to estimate densities marine mammals from their calls and clicks. It is likely that various aspects of these new techniques can be applied to other species and areas.

RELATED PROJECTS

Related projects were conducted by Len Thomas, Vincent Janik, and Steve Martin. These projects are using density estimates derived from our effort to calculate average boing (cue) rate so that estimates of minke whale densities can be derived from seafloor and autonomous hydrophones. We have used

software tools (e.g. boinger) to post-process towed array acoustic data collected during the Mariana Islands and Sea Turtles and Cetacean Survey (MISTCS). Density estimated for calling minke whales were calculated using methods described in this report.

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Table 1. Acoustic based line-transect density estimates calculated using distances from acoustically localized calling minke whales. The assumptions of reduced calling and evasive movement of minke whales were analyzed separately to account for the reduction on localizations near the trackline (which affects how the detection function is modeled). Note that densities for Kauai were 4-5x greater than for the Northern Marianas Islands study area.

Study Location	Assumptions	Study Area (km^2)	Abundance (%CV)	Density (10,000 km^2)	CV (%)
PMRF Kauai	reduced calling	2055	9.72	**37.08**	20%
PMRF Kauai	evasive movement	2055	6.67	**27.51**	19%
N. Marianas	reduced calling	585,800	394	**6.73**	25%
N. Marianas	evasive movement	585,800	345	**5.89**	25%

Table 2.   Results of random forest analysis presented as percent correct classification (highlighted with rectangles) of actual versus predicted locations for boings recorded in Guam and Kauai.

actual location	predicted location		
	Guam	Kauai	n
Guam	81%	19%	70
Kauai	15%	85%	68
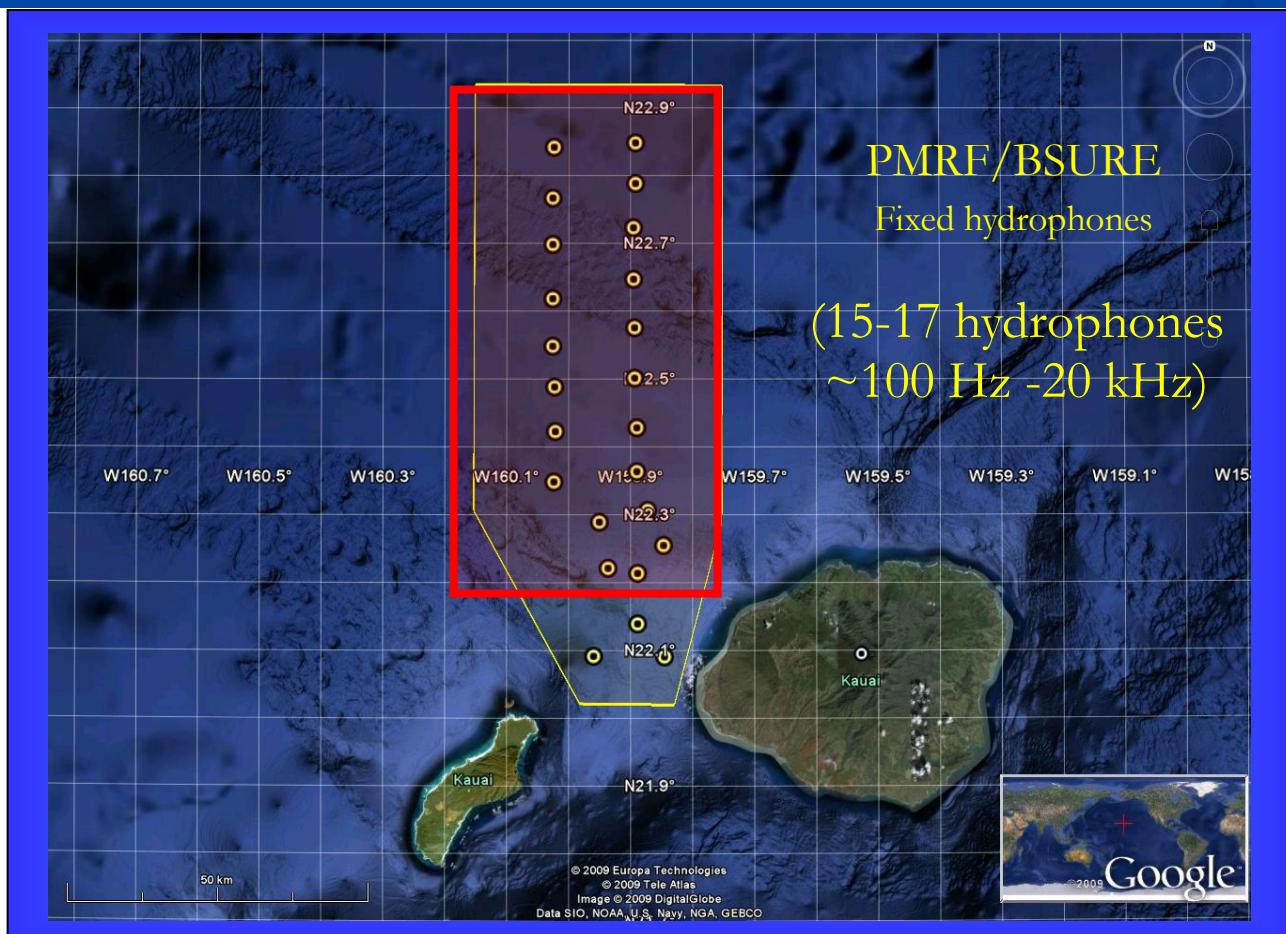
Figure 1. PMRF study area (2055 km²) off Kauai (red box) with PMRF hydrophones (yellow). Locations of hydrophones are approximate to indicate coverage of study area.
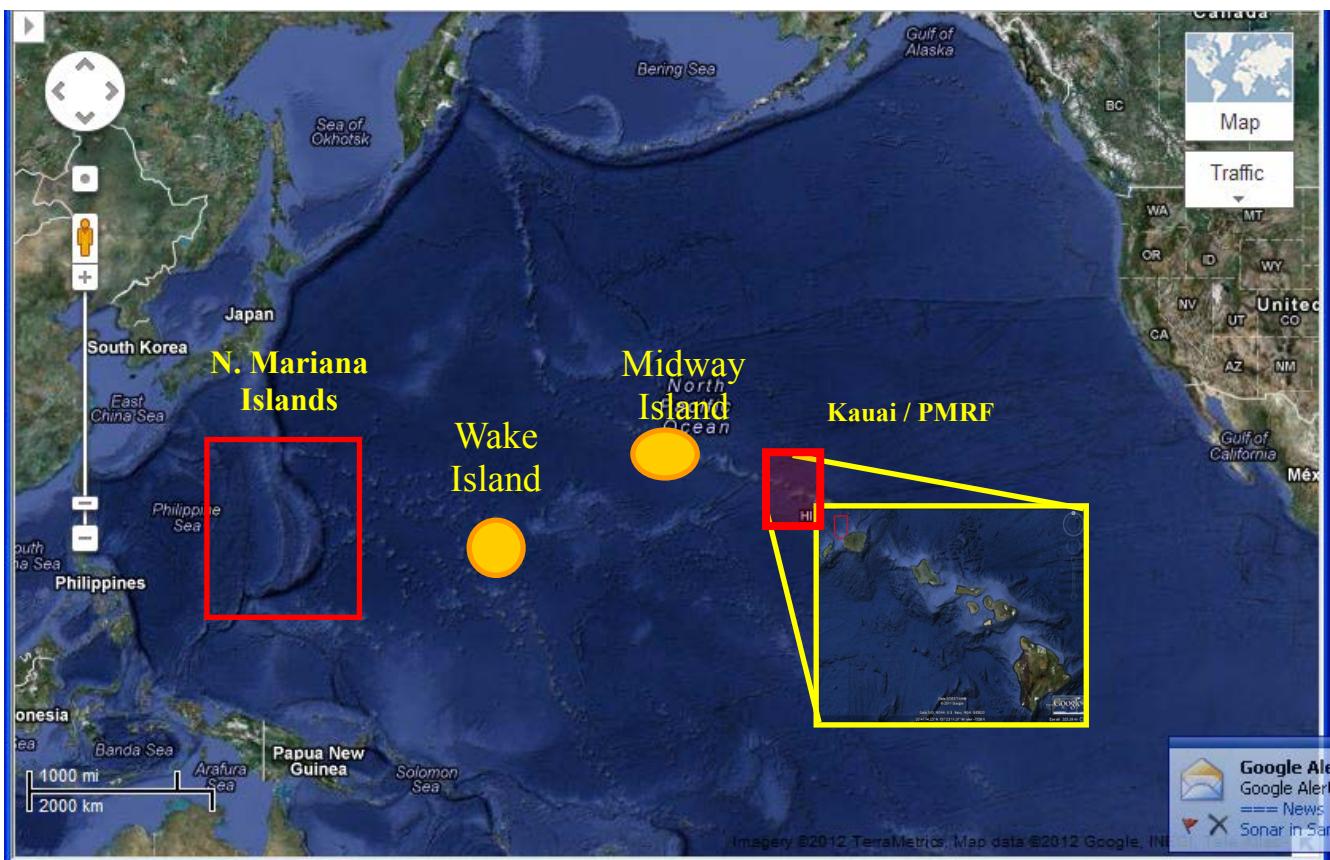
Figure 2. Study locations used for boing characterization/population structure study. Red rectangles indicate study areas where towed hydrophone array data were used. Orange ovals indicate sites where HARP (autonomous) recorder data were used.

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Detection function plot
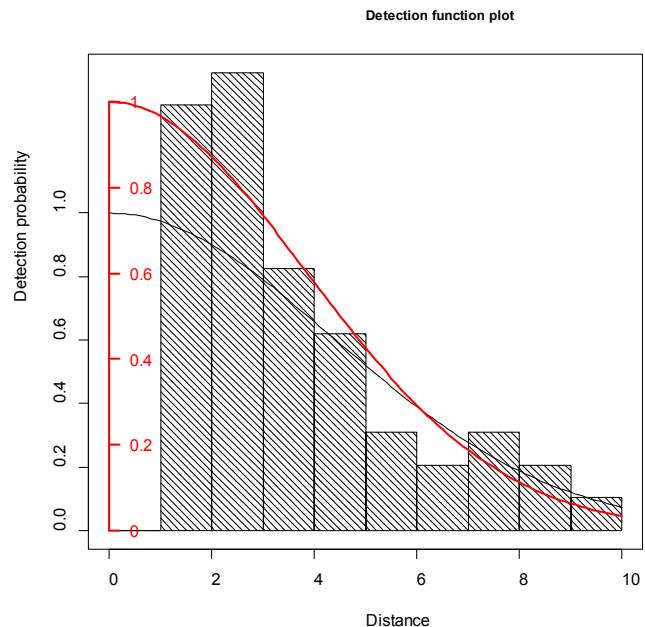
(a) No left truncation (evasive movements).

Detection function plot
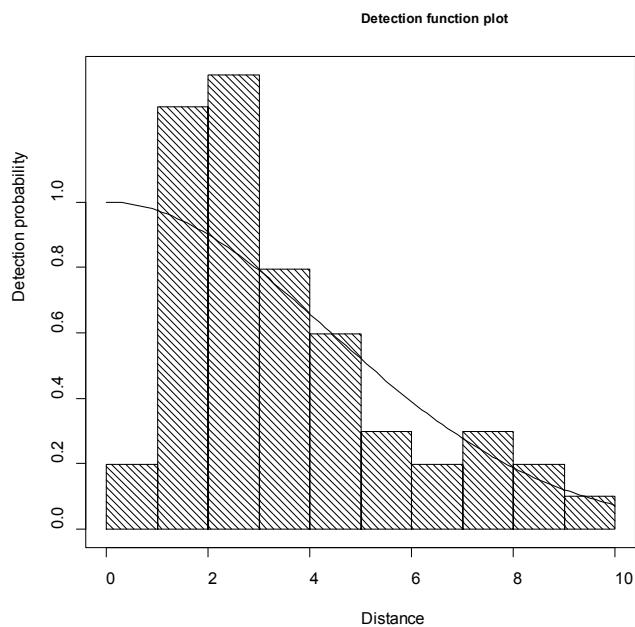
(b) With left truncation (redction in vocalizations).

Figures 3a & 3b. Plots of detection functions fit to the distance data. The two possible explanations for the drop in detections near the trackline were defined as evasive movements and reduction in vocalization rates. Both possibilities were modeled in the two detection functions above.